The Various Inclinations of the Electrical Axis of the Human Heart. Part I.—*The Normal Heart.*

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CONTENTS.

1. *Introductory—Weak and Strong Leads.*

The "normal hearts" dealt with in the present communication are those of the regular workers in this laboratory and of ordinary visitors who have wished to see the electrical effects of their own hearts and who have been good enough to allow me to make use of their records; these have been taken when possible by right and left superior and by right and left lateral leads, so as to afford data for the calculation of the position of the current-axis above and below the heart. No clinical examination of any kind was made in the case of visitors, so that strictly speaking normality of the heart in their case has not been verified. We may, however, assume as probable that the heart of an ordinary active person does not depart widely from the normal. And as a matter of fact the electrocardiograms taken upon such persons are in themselves sufficient evidence of normality to an observer familiar with the signs of abnormality.

In the entire series of normal persons (amounting to about 200) I have examined during the last three years I have only met with five cases presenting "abnormal" cardiograms; of these five, three have volunteered an interest in their own cases that has permitted a careful examination of the heart to be made, in the other two cases no attempt at verification has been made or suggested.

One of the "normal" cases has proved to be particularly interesting, that namely of Thomas Goswell, my former laboratory man, upon whom I made

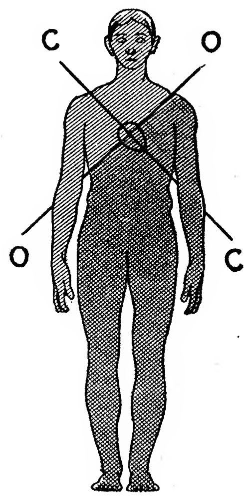
repeated observations during the year 1887 and whose current-axis I then estimated, or rather guessed, as forming an angle of 45° with the vertical line. His normality was, of course, verified at the time. And I have been fortunate enough a few days ago to obtain records of the four necessary leads from which the angle of the current-axis can be calculated. It happens to come out at the value of 45°, which in itself is, in my opinion, proof of normality. And the photograph that was taken of this subject last week as compared with the sketch of the same subject that was used as a class-diagram 27 years ago is in itself sufficient proof of normality as to the state of the heart.

In 1887 the idea occurred to me that it should be possible to utilise the limbs as natural electrodes in relation with more or less opposed aspects of the heart, and so to obtain information concerning the absolutely intact organ. With the aid of Lippmann's capillary electrometer I surveyed all the different pairs of leads that I could think of, and as the outcome of this survey, divided the human body into two unequal parts by means of an imaginary line or equator cutting at right angles a second imaginary line or current-axis crossing the chest obliquely in the direction of the anatomical axis of the heart—itself an imaginary or at least an indefinite line. I figured the current-axis as forming an angle of 45° with the vertical and taking the leads two by two I found that they fell into two sets which I called "favourable" and "unfavourable." On review of these observations it became apparent that in the "favourable" cases, *i.e.* those in which the electric pulse was obvious, the two leads were on opposite sides of the equator, while in the "unfavourable" cases, *i.e.* those in which little or no pulse was visible, both leads were on the same side of the equator. I ascertained by direct observation that of the six possible leads afforded by the four extremities taken two by two, three are favourable (1, 2, 3) and three unfavourable (4, 5, 6) as regards the demonstration of the electrical pulse; and that of the four possible leads from the extremities taken in conjunction with the mouth, three are favourable (7, 8, 9) and only one unfavourable (10).*

Finally the proof of the relation between the normal obliquity of the heart and favourable and unfavourable leads was completed by the investigation of two cases of situs viscerum inversus where in correspondence with the reversed obliquity of axis, the transverse effect between the two hands was observed to be reversed; the right superior and left lateral leads to be favourable; the left superior and right lateral to be unfavourable.

* Waller, "On the Electromotive Changes connected with the Beat of the Mammalian Heart, and of the Human Heart in particular," 'Phil. Trans.,' 1889, p. 169. The principal facts were demonstrated, in 1887, at the First Congress of Physiology, at Bâle.

The facts have been confirmed by all subsequent observers, more or less completely according as they have reviewed more or fewer of the 10 leads, but with one notable exception, viz., the left lateral, as to which I am stated to have been mistaken. Prof. Einthoven in particular has attributed my having classified it as an "unfavourable" or "weak" lead to the comparative slowness of the capillary electrometer;* as a matter of fact I did not make the mistake attributed to me, and I expressly adhere now to my original classification of the left-hand lead with either foot as a "weak" lead. The classification of leads as "strong" and "weak" forms indeed the basis of this paper, in the course of which it will be made apparent that the relatively weak left-hand effect below the heart is an index of the degree of obliquity of the cardiac current-axis.



1. Transverse... { R. hand. / L. hand.
2. Axial .... { R. hand. / L. foot.
3. R. lateral ... { R. hand. / R. foot.
4. L. lateral. ... { L. hand. / L. foot.
5. Equatorial... { L. hand. / R. foot.
6. Inferior ...... { R. foot. / L. foot.
7. L. superior .. { Mouth. / L. hand.
8. L. inferior... { Mouth. / L. foot.
9. R. inferior... { Mouth. / R. foot.
10. R. superior.. { Mouth. / R. hand.

C C denotes the current-axis, O O denotes the equator.

When the survey of these ten leads has been completed, we may reduce them in number for further systematic investigation. The two feet are practically iso-electric: this pair may therefore be neglected. And if we regard the two feet as electrically indifferent, the axial and right lateral leads are equivalent, and one of them may be left out; also, on this assumption, the left lateral and the equatorial are equivalent, and we may drop one out. Then as to the mouth; it is not necessary in a cursory survey to take

* Einthoven ('Pflüger's Archiv,' 1908, pp. 551–2). In my first three cases of 1887 the angles (measured in 1913) are 45°, 51°, and 86°. In Einthoven's two cases of 1908 (measured from the published records on pp. 554–5) the angles are—Ei. = 22° and Fl. = 7°.

all the three "favourable" leads: it is sufficient to compare the "good" hand (left) with the "bad" hand (right) by taking the right and left superior leads. And so I reduce my system of leads to five, as under:—

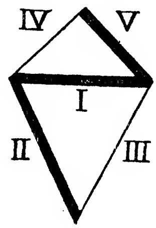
I. Transverse.

II. Right lateral.

III. Left lateral.

IV. Right superior.

V. Left superior.



Note.—In adopting this simplification we should, however, not lose sight of the fact that, for certain finer determinations, the P.D. between the two feet must be taken into reckoning, and that we may not always take as equivalent axial with right lateral and equatorial with left lateral, although for all ordinary purposes this may be done. Also, in the case of the mouth leads, where we shall content ourselves with taking the left superior as the strong lead and neglect the other two strong leads, viz., left and right inferior, we may find it necessary to take into account the small differences that obtain between the three strong leads with the mouth. An idea of their order of magnitude is given by the following example, in which they were carefully measured:—

Right superior	3 mm.	(= 0·00023 volt)
Left superior............	15·3 „	(= 0·00118 „)
Right inferior	16·5 „	(= 0·00126 „)
Left inferior	17·5 „	(= 0·00135 „)

The study of the subject was subsequently taken up by Einthoven and his pupils, whose principal publications appeared in 1895, 1900, and 1908. In 1900 he extended the inquiry to the abnormal heart. In 1903 he devised his string-galvanometer, which, by reason of its superior rapidity, is preferable to the capillary electrometer for these observations. At the same time, Einthoven reduced the six possible leads from the extremities to three, and promulgated what is known as "Einthoven's equation," viz.:—

Lead II (axial)—Lead I (transverse) = Lead III (left lateral),

and represented in the form of an equilateral triangle, of which the heart is the centre. And quite recently* Einthoven has given a construction by which he

* W. Einthoven, "Ueber die Form des menschlichen Elektrocardiogramms," 'Pflüger's Archiv,' 1895, vol. 60, p. 101; W. Einthoven and K. de Lint, "Über das normale menschliche Elektrocardiogramm, und über die capillar-elektrometrische Untersuchung einiger Herz-Kranken," 'Pflüger's Archiv,' 1900, vol. 80, p. 139; W. Einthoven, "Die

synchronises the three records, in order to calculate from their corrected value the magnitude of the angle α that must be formed with the horizontal by a potential difference passing through the centre of the triangle. From this basis Einthoven has calculated that in a particular subject ("Bak") the heart had rotated in the chest around a sagittal axis during the movement of expiration by an angle of $-36°$ (*i.e.* from $\alpha = 76°$ to $\alpha = 40°$, referred to the horizontal).

2. *Determination of the Electrical Axis.*

I have approached this problem of the angle from a different standpoint, namely, from the point of view of my first observations of 1887–9, and the distinction between "favourable" and "unfavourable" leads, or, as I now call them, "strong" leads and "weak" leads. In order to calculate the obliquity of the cardiac current-axis, I took values between a mesial point and the two sides of the body, in fulfilment of the rough notion of a balance of which the two unequally loaded arms, R and L, give an angular deflection of the indicator in relation with a weight-difference between R and L.

In electrical analogy with this idea, I took for calculation the values of the potential differences between leads from the mouth and right hand and between the mouth and left hand. According to this picture, the electrical pivot or zero is an electrode in the mouth, and the weights are the potential differences between the electrode M and the right hand R on one side, and the left hand L on the other, to form the other electrode. These two leads may be referred to as the right superior and left superior respectively, in distinction from analogous leads between hands and feet, which will be referred to as right and left lateral. The formula for calculating the angle α between current-axis and vertical is very simple: $\tan\alpha = (L-R)/(L+R)$, where L and R represent respectively observed magnitudes of potential difference at the outset of systole by the left and right superior leads respectively; for example, with $L = 9$ and $R = 3$,

$$\tan\alpha = \frac{9-3}{9+3} = \frac{6}{12} = 0{\cdot}5, \qquad \therefore \quad \alpha = 27°.*$$

Similar considerations apply to the inferior (or posterior) half of the body, the feet (or either foot if we admit that the small P.D. existing between the

galvanometrische Registrirung des menschlichen Elektrocardiogrammes, zugleich eine Beurtheilung der Anwendung des Capillar-Elektrometers in der Physiologie," 'Pflüger's Archiv,' 1903, vol. 99, p. 472; "Le Télécardiogramme," 'Archives Internat. de Physiol.,' 1906, vol. 4, p. 132; "Weiteres über das Elektrocardiogramm," 'Pflüger's Archiv,' 1908, vol. 22, p. 517; "The different Forms of the Human Electrocardiogram and their Signification," 'Lancet,' March, 1912, p. 853.

* Or, more precisely, 26° 34′ but in this connection α will be given to the nearest degree only.

two feet may be treated as negligible; but by reason of the greater acuteness of the angle subtended by the R and L leads at the inferior lead F, as compared with the superior lead M, a new factor must be introduced into the formula, which is now taken as $\tan \alpha = 2(\mathrm{R}-\mathrm{L})/(\mathrm{R}+\mathrm{L})$, where R and L represent respectively observed magnitudes of the potential differences in the right and left lateral leads. If, for example, the values have been observed, $\mathrm{R} = 12$, $\mathrm{L} = 4$, then

$$\tan \alpha = 2\,\frac{12-4}{12+4} = \frac{16}{16} = 1, \qquad \therefore \quad \alpha = 45^\circ.$$

Put into words, the general conclusion expressed by the two formulæ* for calculating the direction of the cardiac current-axis from the right and left potential difference existing at the outset of systole above and below the heart, is as follows:—The tangent of the angle formed by the current-axis with the vertical is proportional to the difference between the potential differences of the strong lead and the weak lead divided by the sum of these two differences.

The error of angle by error of measurement of the spike is, with most records, inconsiderable, except in the case of the left lateral lead, when its direction is doubtful. When it consists of a small positive followed by a large negative peak we may hesitate whether to take into our formula the small positive or the large negative value; in such case of doubt it is advisable to calculate the angle for both values. If, in a doubtful case, the right lateral is smaller than the transverse spike, the negative value of the left lateral should be taken in the formula; if the right lateral is larger than the transverse, the positive value of the left lateral should be taken. But I do not attach much value to the numerical result in such a case (*vide infra* fig. on p. 520, the case of Dr. E.).

In most normal records, where the ventricular spike is clearly positive, there is no difficulty in measuring out its values for the right and left hands. I have not taken into reckoning the small preliminary negative movement ("Q") by which the positive movement is more or less distinctly preceded. This negative movement, while forming part of the systolic change of potential, occurs before the ventricle has begun to contract.

As far as it is possible to judge from simultaneous records by the R and L lateral leads, taken on a film travelling at the rate of 130 mm. per second, the two spikes R and L, when both are positive, culminate synchronously.

* The two formulæ might have been expressed by a single general formula, as follows: $\tan = \cot \theta\,(\mathrm{S}-\mathrm{W})/(\mathrm{S}+\mathrm{W})$, where θ stands for the angle taken at M or at F, and S, W for the values of strong and weak leads respectively. But the two special formulæ are preferable for practical calculations with a conventional direction of currents.

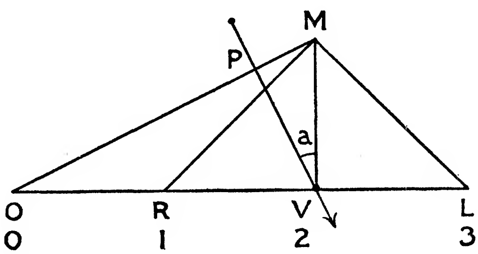
Where the spike is positive on the right side and negative on the left, the positive maximum was reached 0·006 sec. earlier than the negative minimum, and, as far as can be judged from the record, the two events appear to commence synchronously. From the inspection of the left lateral spikes of intermediate type, + −, it appears that the transition from 1 to 4 is by a retrograde encroachment of − upon +.

3. *Proof of the Formulæ :* $\tan\alpha = \dfrac{L-R}{L+R}$, $\tan\alpha = 2\dfrac{R-L}{R+L}$.

The normal difference between "strong" and "weak" leads is evidently dependent upon the normal obliquity of the heart. The principal electrical event of the beat, *i.e.* the systolic spike, is the resultant along a line BA or CC representing the current-axis, of all the component differences of potential existing in the heart muscle at the outset of systole. Comparing the magnitudes of the spikes of the two sides it is obviously in correspondence with the normal tilt of the heart's axis that the left superior is the "strong" lead and the right superior the "weak" lead.

From the observed magnitude of the two spikes, right and left, it is easy to construct a geometrical figure by means of which the numerical value of the obliquity can be expressed in terms of the angle made by the current axis CC with the vertical line MV.

In the triangle MRL, the sides MR, ML indicate the right and left superior leads, M being the mouth, R the right hand, L the left hand. Actually, in relation to the heart, these leading points are to be regarded as sections through the neck and shoulders, and for convenience of calculation we shall take the angle at M = 90°, so that MV = ½ RL = RV. Taking, *e.g.* the right-hand spike = 1 and the left-hand spike = 3, we have



at M the potential = 0, at R the potential = 1, at L the potential = 3. Projecting the potential of M on to the horizontal line LR produced to O and taking the position of the point O such that the length OR shall represent the potential difference between M and R, and OL the potential difference between M and L, we have MO as the line of zero potential. A

line VP, drawn perpendicular to this zero line MO, gives the position of the current-axis CC forming with the vertical MV an angle, which call α.

The angle MOV $= \alpha$; $\tan \alpha = \tan$ MOV $=$ MV/OV $= \frac{1}{2} = 0{\cdot}5$. Therefore $\alpha = 26^\circ\ 36'$; or otherwise: since MV $= \frac{1}{2}(\mathrm{L}-\mathrm{R})$ and OV $= \frac{1}{2}(\mathrm{L}+\mathrm{R})$, we may write $\tan \alpha = (\mathrm{L}-\mathrm{R})/(\mathrm{L}+\mathrm{R})$, or, in words, the required angle α is an angle having for its tangent the fraction of which the numerator is the difference between the spike of the strong lead and that of the weak lead, and the denominator their sum.

The formula holds good for negative values of the weak lead, as can easily be shown by a geometrical construction. But an example will be sufficient. Let -1 be the value observed by the weak lead R, and $+3$ that for the strong lead L.

$$\tan \alpha = \frac{\mathrm{L}-\mathrm{R}}{\mathrm{L}+\mathrm{R}} = \frac{3+1}{3-1} = 2, \qquad \therefore\ \alpha = 64^\circ.$$

Finally, we may mention two particular cases that are occasionally observed. If the weak lead R $= 0$, then

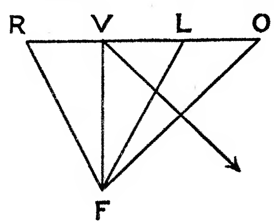
$$\tan \alpha = \frac{\mathrm{L}-0}{\mathrm{L}+0} = 1, \qquad \therefore\quad \alpha = 45^\circ.$$

If the weak lead R is negative and greater than the strong lead we shall have α greater than 90°, *i.e.* a current-axis upwards from right to left. This case may also occasionally be met with as an extreme case of the "cor breve et molle," *e.g.* let R $= -2$ and L $= 1$,

$$\tan \alpha = \frac{\mathrm{L}-\mathrm{R}}{\mathrm{L}+\mathrm{R}} = \frac{1+2}{1-2} = \frac{2}{-1} = -2, \qquad \therefore\quad \alpha = 116^\circ.$$

An essentially similar principle of calculation is applicable to the data afforded by leads from the four extremities—the two hands and the two feet—with, however, certain modifications.

The modifications to be taken into account are: (1) that the two feet are assumed to be equipotential and represented by a single foot F at the inferior angle of the triangle RLF in analogy with the point M of our first triangle; (2) that therefore we are to regard as equivalent the right lateral with the axial leads, and the left lateral with the equatorial; (3) that we have to remember that with the extremities, R is the strong lead, L the weak lead; and (4) that the conditions require us to take at F a more acute angle than in the case of the superior triangle we have taken at M.



In the figure representing the inferior triangle the length VF has been taken as equal to the length RL, *i.e.* twice RV. The formula now runs: $\tan \alpha = 2(\mathrm{R}-\mathrm{L})/(\mathrm{R}+\mathrm{L})$, where R and L stand for the

magnitudes of the systolic spikes of the right lateral and left lateral leads respectively. (In the illustration we have taken R = 3 and L = 1.)

It is scarcely necessary to give the geometrical construction from which the formula is derived. As in the previous case we have tan $\alpha =$ the difference R−L divided by the sum R+L and multiplied by FV/RV, the cotangent of $\frac{1}{2}$ the angle RFL. For the superior triangle we took MV/RV = 1, for the inferior angle we take FV/RV = 2.

The application of our formula may be illustrated by examples. It has been observed, *e.g.*, that R = 3 and L = 1; then

$$\tan\alpha = 2\frac{3-1}{3+1} = \frac{4}{4} = 1, \qquad \therefore \quad \alpha = 45^\circ.$$

It has been observed, *e.g.*, that R = 3 and L = −1; then

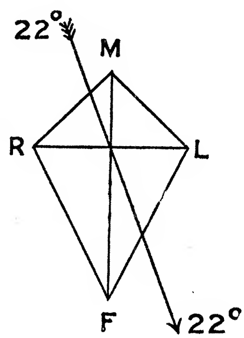
$$\tan\alpha = 2\frac{3+1}{3-1} = \frac{8}{2} = 4, \qquad \therefore \quad \alpha = 76^\circ.$$

We shall now apply our formula to some actual cases:—

The Case of B. O. B.

(Inspiratory Values.)

Right superior	7·5
Left superior	17·5
(Transverse	16)
Right lateral	23·5
Left lateral	15·5

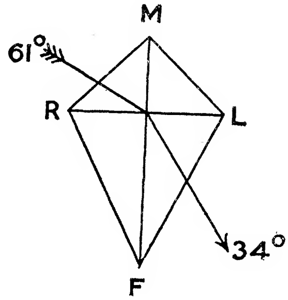


Sup. $\quad \tan a = \frac{L-R}{L+R} = \frac{17·5-7·5}{17·5+7·5} = \frac{10}{25} = 0·40, \quad \therefore \quad a = 22^\circ.$

Inf. $\quad \tan a = \frac{R-L}{R+L} = 2\frac{23·5-15·5}{23·5+15·5} = \frac{16}{39} = 0·41, \quad \therefore \quad a = 22^\circ.$

The Case of J. C. W.

Right superior	−2
Left superior	7
(Transverse	11)
Right lateral.........	14
Left lateral	7

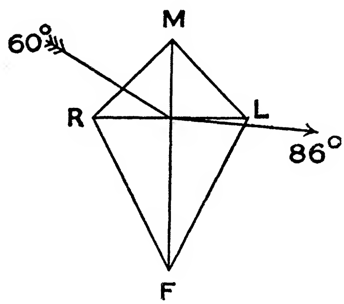


Sup. $\tan a = \frac{7+2}{7-2} = \frac{9}{5} = 1{\cdot}8, \quad \therefore \quad a = 61^\circ.$

Inf. $\tan a = 2\,\frac{14-7}{14+7} = \frac{2}{3} = 0{\cdot}67, \quad \therefore \quad a = 34^\circ.$

The Case of A. D. W.

Right superior ...	−2
Left superior	7·5
(Transverse	12·5)
Right lateral	10
Left lateral.........	7·5



Sup. $\tan a = \frac{7{\cdot}5+2}{7{\cdot}5-2} = \frac{9{\cdot}5}{5{\cdot}5} = 1{\cdot}73, \quad \therefore \quad a = 60^\circ.$

Inf. $\tan a = 2\,\frac{10+7{\cdot}5}{10-7{\cdot}5} = \frac{35}{2{\cdot}5} = 14. \quad \therefore \quad a = 86^\circ.$

4. *Apparatus Used.*

In these observations I have used:—

(1) An early model by Edelmann of Einthoven's galvanometer with a platinum fibre of 2000 ohms resistance, and platinum electrodes dipping in normal saline.

(2) An oscillograph (Bock-Thoma model) by Thoma, of Munich, with a condenser of large capacity (10 and 20 mf.) in circuit, and, as before, platinum electrodes in saline.

Each of these instruments possesses advantages and disadvantages; for the special purposes of the present observations the second instrument has proved to be the more convenient. By the use of platinum electrodes

(which in themselves act as a condenser of considerable polarisation capacity, *e.g.* in one measured case about 10 mf.), supplemented by an added condenser in circuit, we are rendered independent of alterations of resistance; the galvanometer is practically converted into an electrometer.

5. *Influence of Position and of Respiration.*

The influence of slight alterations of position of the body upon the electrical record both as regards form and as regards amplitude is trifling. I did not notice any such influence in my first observations. Einthoven has subsequently found that in the recumbent posture turning from the left over to the right side alters the form of the first ventricular wave from simply + to + −. But in view of the calculations to be made from the relative amplitudes of the left and right records, I thought it necessary to re-try this point in order to learn whether alterations of position great or slight cause alterations of amplitude. I found that slight alterations are negligible, but that great alterations, such as from standing to sitting, and lying either on the back or on the face, or on one or other side, alter the amplitude and the angle. I have therefore taken all observations from persons in the most convenient position, *i.e.* sitting.

The effect of considerable alterations of position is evident from the following observation, in which the transverse, right and left lateral records were taken of the subject B. O. B. in the standing, sitting, and lying positions. The points that come out most clearly on review of this group of records are that lying on the left side as compared with lying on the right side diminishes the angle α, as shown by increase of the left lateral spike and diminution of the transverse spike. This alteration is also brought about by muscular exercise (*vide infra*), and the reverse alteration, viz., increase of the angle α, is caused by distension of the stomach.

B. O. B. (Feb. 26, 1913).

	Pulse frequency.	Transverse.	R. lat.	L. lat.	α.*
					Insp. Exp.
Standing	74	14	14	7·5	31 (29 45)
Sitting	64	15	14	5	43 (40 53)
Lying on back	62	15	18	7·5	40 (39 50)
Lying on right side...	62	17	18	5	48 (42 50)
Lying on left side ...	60	11	16	10	25 (25 27)

* The values of α given in parentheses are the *approximate* inspiratory and expiratory numbers calculated from maximal and minimal values of the R and L spikes.

There is no more than a general correspondence of inclination between the line drawn through the heart to represent its anatomical axis and the line or lines representing its electrical axis. This is hardly surprising when we realise how indefinite is the anatomical axis and upon what data and assumptions the determination of the electrical axis depends. I regard the latter as the more definite of the two lines; it gives expression to the functional resultant at the outset of contraction of the living organ, and indicates by considerable and definite variations changes of axis that are difficult to settle either *post mortem* or by skiagram during life.

6. *Tone of the Heart Muscle.*

I attribute considerable importance to the tone of the heart muscle as regards position of the heart and of its electrical axis. With soft muscle the heart is sessile on the diaphragm, and the axis, as calculated from right and left lateral spikes, is approximately horizontal. (See fig. on p. 520, the case of Dr. E.) With hard muscle the heart is more nearly erect on the diaphragm, and the axis, calculated as before, is more nearly vertical. (See fig. on p. 521, the case of Dr. D.)

Influence of Respiration.—I paid no attention in my first observations to the effect of respiration upon the electrocardiogram. This effect has since been carefully studied by Einthoven, who has shown that with forced inspiration the amplitude of the record of Lead III (left lateral) is increased, while that of Lead I (transverse) is diminished; the changes in Lead II (axial) he describes as very slight. My observations are on the whole in harmony with those of Einthoven, but their full discussion must be postponed. For the purpose of the present communication it will be sufficient to state that I have found it necessary for any exact estimation of the angle to take into account the phases of ordinary respiration, which briefly are of the following character:—

With inspiration the left superior and the right lateral records are diminished, the right superior and the left lateral records are increased. In taking out values of R and L for a careful determination of α by the appropriate formulæ it is therefore necessary to take for its inspiratory value the smallest values recorded of the left superior and right lateral leads and the largest values recorded of the corresponding right superior and left lateral leads. For the expiratory value we must take out the largest values of the left superior and right lateral and the smallest values of the right superior and left lateral. But this troublesome correction is in most cases superfluous. It can, however, occur that normal respiration brings out differences of amplitude that lead to differences of angle of 10°, *e.g.* the case of J. B. F.,

where I first noticed that the correction might be required, and I have therefore thought necessary to say that I have been alive to the error that might be made by neglecting the correction where it was evidently of moment.

The type of the electrical pulse by different leads is remarkably individual and constant. Thus it has not altered, as far as I can tell, in the cases of A. D. W. and A. M. W. and T. Goswell between 1887 and 1913.

Nevertheless, temporary variations do occur in a given individual—variations of frequency of course, but also variations of form and variations of the angle α. I think that such variations are attributable to greater and lesser repletion of the stomach and of the several cavities or of the two sides of the heart. In at least two instances where the angle α has been found greater in the same individual at one time than at another, I have associated the value of the angle with the state of health. But the discussion of this important point cannot profitably be entered upon until the effect of respiration has been fully considered; and it properly belongs to a future communication on the pathological significance of the angle α.*

7. *The Influence of Muscular Exercise.*

As was to be expected, the frequency and character of the electrical pulse are altered with muscular exertion.

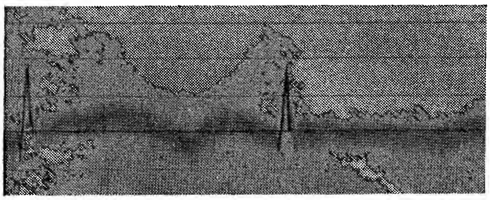
Electrocardiograms afford indeed the most convenient available means of exactly counting the pulse, and of measuring out the working-time of the heart from varying relations between length of systole and length of diastole. But the primary object of this paper is to study variations of the angle α, and in this connection it appears that any variations that might be expected to result from variations of repletion of the several cavities is masked by the large variations caused by deepened respiration—especially inspiration. The detailed consideration of the influence of exercise must therefore be subordinated to that of the influence of respiration, and at present it will be sufficient to give the results of observation on one subject (B. O. B.) in illustration of the fact that muscular exertion indirectly through modified respiration, and perhaps also directly by modifying the repletion and shape of the heart, does actually bring about considerable modifications of the electrocardiogram and of the angle α as calculated from its right and left hand values.

* A further complication arises where the left lateral lead is negative; the correction has then to be taken in the opposite sense, because whereas a positive left lateral is increased with inspiration, a negative left lateral is diminished. The same holds good for a negative right superior record. But the discussion of these points must be postponed.

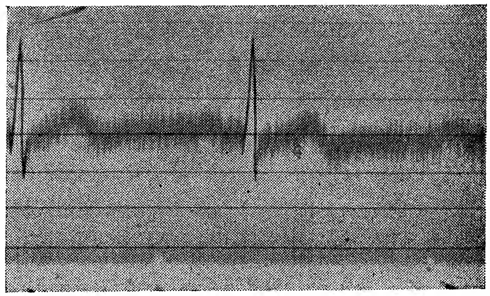
Dr. E.—The superior angle a can be estimated without difficulty from the values of the right and left superior spikes—

$$\tan a = \frac{12{\cdot}5 + 7{\cdot}5}{12{\cdot}5 - 7{\cdot}5} = \frac{20}{5} = 4. \quad \therefore \; a = 76^\circ.$$

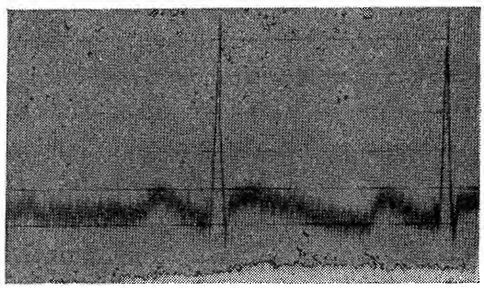
But the mixed character of the right and left lateral spikes, viz., positive followed by negative, does not afford assured data for calculation (see text, p. 512). Taking into the formula the positive values 7·5 and 5, the angle comes out as 22°. Taking a positive value 7·5 and a negative value −25, $a = 105^\circ$. Taking the negative values −12·5 and −25, $a = 34^\circ$ of reversed current direction. But I place no reliance on these figures.



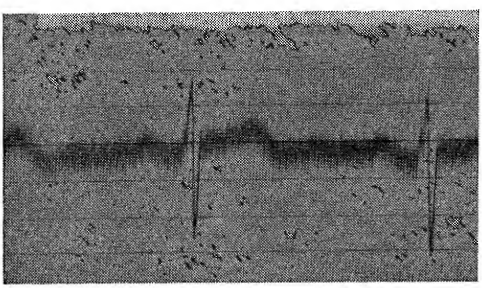
Right superior.



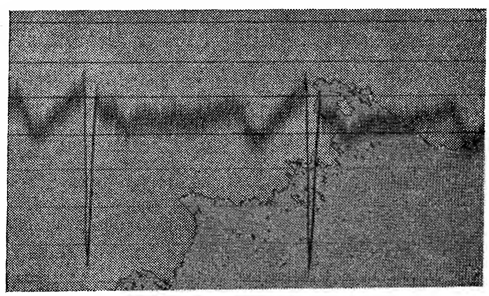
Left superior.



Transverse.



Right lateral.

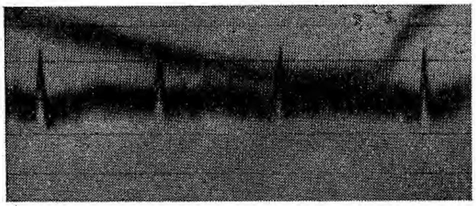


Left lateral.

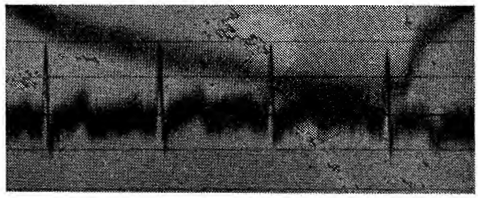
Dr. D.—In this case the electrocardiograms were taken with a simultaneous record of the respiratory movements, and the measurements are given for the same (inspiratory) position in each case. Upon another occasion the R. and L. values were found to be 20 and 15, *i.e.* the inferior a came out = 16°, but no attention was then paid to the phase of respiration. In the accompanying records the values are as under :—

$$\textit{Sup.} \quad \tan a = \frac{7{\cdot}5-5}{7{\cdot}5+5} = 0{\cdot}2. \quad \therefore a = 11^\circ.$$

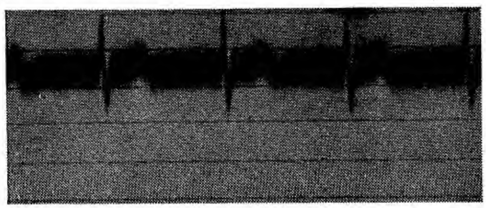
$$\textit{Inf.} \quad \tan a = 2\,\frac{22{\cdot}5-20}{22{\cdot}5+20} = 0{\cdot}12. \quad \therefore a = 7^\circ.$$



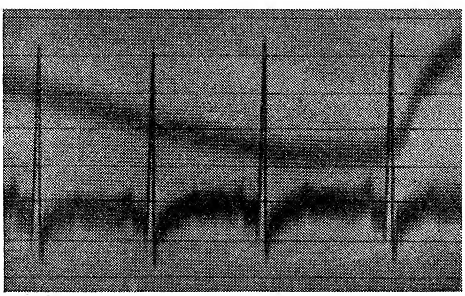
Right superior.



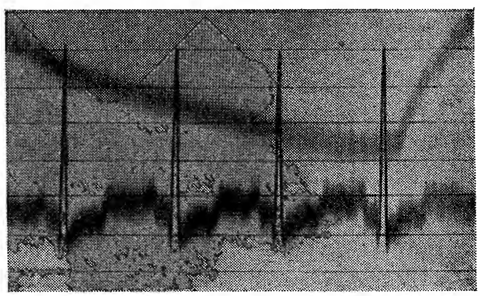
Left superior.



Transverse.



Right lateral.



Left lateral.

	Pulse frequency.	Transverse.		R. lat.		L. lat.		α.	
		Insp.	Exp.	Insp.	Exp.	Insp.	Exp.	Insp.	Exp.
At rest	66	10	11	13	15	7	5	31°	45°
Immediately after exertion, 2000 kgrm. in 35 secs.......	146–126	7·5	12·5	12	14	10	5	10°	44°
Two or three minutes later...	98–96	10	15	13	15	9	5	20°	45°

	Pulse frequency.	R.	L.	α.
Normal	96 to 86	11	2·5	52°
			Exp. Insp.	Exp. Insp.
Second minute	120	12·5	5 to 10	41° to 12°
Fifth minute	104	14	3 ,, 5	52° ,, 43°
Thirtieth minute ...	72	12·5	2·5	53°

The inferior angle α is diminished in consequence of muscular exertion.

8. *The Influence of Food.*

From measurements taken on the same individual before and after food, the angle α has come out greater in the latter than in the former state. But the numerical estimation of this difference cannot be discussed with profit apart from the consideration of the respiratory variations of angle. In the case of B. O. B. the difference has come out = 10°, the actual measurements having been as under:—

	Pulse frequency.	Transverse.	R. lat.	L. lat.	tan α.	α.
Before dinner	62	11	12·5	6	0·70	35°
After dinner	70	12·5	12·5	4	1·02	45°

The left lateral is smaller with a full stomach.
The right lateral is not appreciably altered.
The transverse is increased.
The angle α is increased.

9. *Thoracic Leads.*

The preceding considerations dealing with leads from the mouth and extremities apply to the current-axis in the frontal plane. Similar considerations can be applied for measurement of the current-axis in the antero-posterior (sagittal) plane, and we may calculate superior and inferior values of α by the same formulæ as those taken for their values in the frontal plane.

To compare effects in the sagittal plane, the leads to be taken are :—

Mouth to precordium and mouth to back for the upper part of the body; back to foot and precordium to foot for the lower part. We can calculate the value of an angle α formed by the current-axis and the vertical in the antero-posterior or sagittal plane, by taking the values of the two upper and two lower spikes. And without laying stress upon the precise values obtained for the angle it is satisfactory to find that the arrow representing its position and direction comes out from the calculation conformably with what might be anticipated.

To complete our picture of the current direction we may compare effects horizontally in transverse section across the body ; this can be done roughly by the leads from precordium and back to the right and left hands, or better, by taking the effects from four symmetrical leads encircling the chest on a level with the heart.

This symmetrical arrangement of electrodes gives a more satisfactory set of values than is afforded by the two hands with the front and back of the chest, which gives values in an oblique and principally frontal plane, as is illustrated by the following group of measurements :—

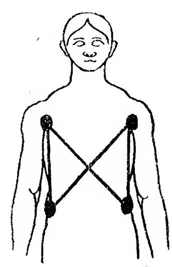
B. O. B. connected to an oscillograph by large (100 × 75 mm.) electrodes on the right and left sides of the chest, and by the right and left hands dipping in saline, gave the following values :—

1. $\left\{\begin{array}{l}\text{Right hand}\\ \text{Right side}\end{array}\right\} +10.$

2. $\left\{\begin{array}{l}\text{Left hand}\\ \text{Left side}\end{array}\right\} +7 \cdot 5.$

3. $\left\{\begin{array}{l}\text{Right hand}\\ \text{Left side}\end{array}\right\} +22 \cdot 5.$

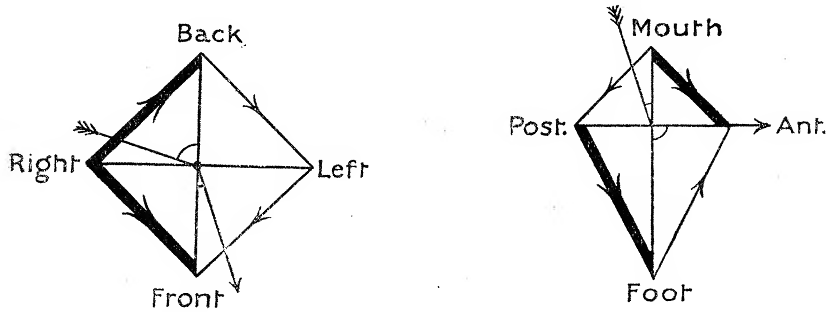
4. $\left\{\begin{array}{l}\text{Left hand}\\ \text{Right side}\end{array}\right\} \begin{array}{l}+2 \cdot 5.\\ -5.\end{array}$



At first sight these results appeared rather perplexing, but their obscurity disappears when we reflect that leads from the hands are, as regards the heart, equivalent to leads from the shoulders, and plan the results accordingly along the lines of a frontal diagram. We then realise that of the four leads, the 3rd, being "axial" as regards the heart, must be the "strongest" lead, and the 4th lead, being "equatorial," must be the "weakest" lead.

In a transverse section of the thorax, *i.e.* in the horizontal plane with the body in the erect posture, similar differences obtain between the two sides. Taking leads from the precordium and first the right then the left hand, we

find that the first lead is stronger than the second. Taking leads from the back of the chest, and first the right then the left hand, we find that the



first lead is positive, the second small. Taking, *e.g.* the values observed for these four leads in the case of B. O. B. the angles come out as follows:—

$$\tan\alpha = \frac{16-7{\cdot}5}{16+7{\cdot}5} = 0{\cdot}36, \qquad \therefore \quad \alpha = 20^\circ,$$

$$\tan\alpha = \frac{7{\cdot}5+5}{7{\cdot}5-5} = 5, \qquad \therefore \quad \alpha = 79^\circ.$$

The angle formed above the heart by the current-axis with the vertical in this plane can be estimated from the relative values of the spike in the two leads mouth-precordium and mouth-back. Thus, *e.g.* in the subject B. O. B., the values of the spike in these leads are: anterior $= 25$, posterior $= 10$, from which our formula for the superior triangle gives $\tan\alpha = (25-10)/(25+10) = 15/35 = 0{\cdot}43$, so that the required angle $\alpha = 23^\circ$. The angle below the heart can be obtained by calculation from the values observed in the two leads precordium-foot and back-foot. In the case of B. O. B. these values are: anterior $= -10$, posterior $= 10$;

$$\tan\alpha = 2\,\frac{10+10}{10-10} = \infty\,, \qquad \therefore \quad \alpha = 90^\circ.$$

This result may be taken as indicating that for the superior part of the heart and body the algebraic sum of current is to be pictured as an arrow directed forwards and downwards at an angle of 23° with the vertical; while for the inferior part of the heart and body the current-axis is represented by an arrow directed horizontally forwards at an angle of 90° with the vertical.

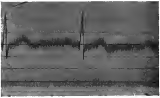
I have tabulated, from my laboratory notes and records of "normal" subjects, the values of right and left hand records, and of the angle α calculated from them.

Values of α calculated from Workers in and Visitors to the Physiological Laboratory.

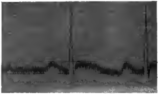
No.		Age.	Trans-verse.	Right superior.	Left superior.	α superior.	Right lateral.	Left lateral.	α inferior.
						°			°
1	Thomas Goswell	53	8	0	8	45	9	3	45
2	A. D. W.	56	12	−2	7·5	60	10	− 7·5	86
	Do.		12·5	−5	10	72	7·5	−15	108
3	A. M. W.	53		−3	8	66	13	3	47
4	A. G. W.	27	5	6	8	8	16	18	−10
5	W. W. W.	24	8·5	0	9·5	45	10	− 1·5	70
6	M. D. W.	26	11	2	10·5		6·5	− 8	93
7	J. C. W.	21	11	−2	7	61	14	7	34
8	B. O. B. .... (Insp. values)	20	14	7·5	17·5	22	23·5	15·5	22
		29					9	3	45
9	A. S.		5	0	5	45	5	+ 1	53
								− 5	90
10	W. L. S.		5				10	8	13
			8	2·5	9	29	10	5	33
11	J. A. G.	46	18	5	17·5	29	8	− 4	81
	Do.		18	4	16	31	Insp. 12	−10	80
							Exp. 16	− 6	83
12	G. E.	29		2	7·5	30	22·5	17·5	14
13	J. S.			0	15	45	17·5	10	28
	Do.						15	7·5	33
	Do.						Exp. 20	7·5	42
							Insp. 17	11	23
14	Dr. G.			5	10	18	12·5	15	−10
	Do.			5	7·5	11	10	10	0
15	Dr. R. W.		12	−2·5	7·5	64	5	2·5	33
								−10	99
16	Dr. H. D.		5	5	7·5	11	20	15	16
	Do. .... (Insp. values)						22·5	20	7
17	Dr. E.			−7·5	12·5	76	7	5	102
								−17	
	Do.		20	−7·5	12·5	76	+ 7·5	+ 5	105
							−12·5	−25	
18	Dr. A.		5				15	16	−4
19	Dr. L.			−5	10	72	5	−10	99
20	Nurse R.	20	7				12	6	34
21	P. W.	20	6				15	12	12
22	J. B. F.	48					Exp. 22·5	12·5	30
							Insp. 18·5	15	12
23	Dr. G.	45		−2·5	10	59	Exp. 20	6	36
							Insp. 17	8	47
	Do.			−4	12	64			
24	Sir D. F.	60	6	0	6	45	+ 2	+ 1	34
25	Mr. S. W.	55		−7·5	12·5	76	15	7·5	34
26	Dr. G. B.						10	4	40
27	G. E.	30	7·5	2	10	34	12·5	6	35
	Do.						15	6	41
28	Miss F.	25	9	2·5	8·5	29	12	7	28
29	Mr. G.						7	6	9
30	T. S. .... (Situs inversus)						10	12	−10
31	Captain E.						9	− 4	87
32	Dr. V.	56		2·5	10	31	Insp. 15	7·5	34
							Exp. 17·5	5	48
33	G. R. M.	29		10	4	24	Insp. 12·5	7·5	Insp. 27
							Exp. 13·5	6	Exp. 38
34	Dr. S. S.	45					12	1·5	58

No.		Age.	Trans-verse.	Right superior.	Left superior.	α superior.	Right lateral.	Left lateral.	α inferior.
						°			°
35	Miss E. B. G. R,		10	1	8	38	Insp. 8 Exp. 9	4·5 3·5	29 41
36	Miss M. F. H. ...		12	−4	12·5	63	9	− 4	70
37	Miss M. M. A. ...		15	−2	14	52	7	− 7	90
38	Miss M. G. B. ...		9	2	10	34	12	4	45
39	Miss N. L.		10	−2	10	60	9	2	52
40	Miss P. W.		5	4·5	7	33	8	6	16
41	Miss H. S..........		3	2·5	6	22	10	6	27
42	Miss H. H.		7·5	0	8	45	7	4·5	23
43	Miss M. E. F. ...		7·5	5·5	0·5	40	9	4	38
44	G. W.	50	8				9	3	45
45	L. B.	35	6				Exp. 10 Insp. 9·5	6 7	27 17
46	Mrs. W.............		7				Exp. 10 Insp. 9·5	5 6	34 24
47	Mr. A. A.		6				Exp. 8 Insp. 7·5	4 5	34 22
48	Sir T. L. B.		15	−2	14	53	7·5	− 6·5	88
49	M. M.			3	9	27	15	10	22
50	Prof. H.		10	2	10	34	13	5	42
51	Dr. M.	46	6	2	7·5	30	17·5	14	12
52	Dr. K.		6	−2	6	64	+ 5	+ 3	27
53	Dr. G. O.		12·5	−3	13	58	7	− 5	85
54	Prof. M.	54	6	−0·5	5	50	10	4	41
55	T. H. K.		6	2	7	29	15	10	22
56	Dr. W.		4	2·5	5	18	6	3	34
57	Miss N. T.	c. 20	5	−0·5	5·5	50	9	4	38
58	Miss G. H.	c. 20	7·5	1	9	39	Insp. 15 Exp. 16·5	8·5 7	29 39
59	Miss L.	c. 20	6	1	5	34	Insp. 10 Exp. 11	6·5 5	23 37
60	Dr. H.	c. 50	8				5·5	− 2·5	37

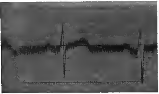
Right superior.



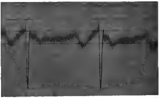
Left superior.



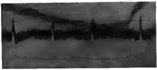
Transverse.



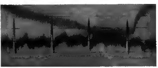
Right lateral.



Left lateral.

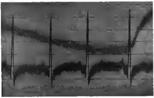


Right superior.

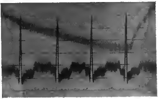


Left superior.

Transverse.



Right lateral.



Left lateral.